MTADS Data Analysis System Migration
ESTCP Project MM-0328

Final Report

David Wright, AETC Incorporated

Herb Nelson, Naval Research Lab

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* AETC, Inc., Raleigh, NC 27513

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List of Acronyms

3-D	Three Dimensional
AMTADS	Airborne adjunct of the Multi-sensor Towed Array Detection System
ASCII	American Standard Code for Information Interchange
AVR	One of the standard NMEA sentences
DAQ	Data Acquisition System
DAS	Data Analysis System
DEM	Digital Elevation Model
DoD	Department of Defense
ESTCP	Environmental Security Technology Certification Program
GPS	Global Positioning System
HAE	Height Above Ellipsoid
H_agl	Height Above Ground Level
IDL	Inetractive Data Language
MTADS	Multi-sensor Towed Arra Detection System
NMEA	National Marine Electronics Association
PPS	Pulse Per Second
RS232	Electronic Industries Alliance Recommended Standard 232
TOA	Time of Applicability
UTC	Coordinated Universal Time
UTM	Universal Transverse Mercator
UXO	Unexploded Ordnance
WGS84	World Geodetic System, 1984 Revision

1 Introduction

1.1 Background

Unexploded ordnance (UXO) continues to present serious environmental challenges to Department of Defense (DoD) facility managers. Prior ESTCP- and SERDP-funded programs have resulted in the successful development and demonstration of state-of-the-art vehicular and airborne towed arrays (the Multi-Sensor Towed Array Detection System, known as MTADS and the airborne adjunct to this system) for large-scale UXO geophysical surveys. A significant component of these programs was the development of a prototype Data Analysis System (DAS). This development was conducted in the IDL environment. The DAS software provided the utilities required for data reduction, physics-based target analyses, and generation of prioritized dig sheets. The MTADS airborne adjunct (AMTADS) development program, ESTCP project MM-0031,[1] required that these utilities position the data in three dimensions, incorporate the 3-D positions in the analyses, and convert the derived estimate of the vertical position of each target to depth below ground. The prototype DAS was used successfully in meeting the goals of the development and demonstration of the airborne MTADS. However the prototype software posed obstacles with respect to commercialization of the airborne MTADS technology, because it required continuous support by key personnel involved in the original software development. Because the IDL programming environment is not commonly used by the geophysical community, initial training and long term support for the prototype would require considerable expense and effort for potential commercial users of the system.

1.2 Objective

The objective of this project was to transfer the AMTADS DAS utilities to a commercially available geophysical data processing environment to facilitate the commercialization of the AMTADS technology. This environment, known as Oasis montaj™ (Oasis) is provided and supported by Geosoft Inc. and is widely accepted by the geophysical community, including UXO service providers. The choice of this environment provides ready access to members of the geophysical community that are already proficient in working with data in this environment, thus reducing the learning curve required for successful transition of the AMTADS technology. It also provides a mechanism for the long term support of this software and eliminates the reliance on one or two key individuals for continued software development support.

2 Technology Description

2.1 Technology Development and Application

2.1.1 Processing Flow Overview

The primary goal of a geophysical UXO survey is to provide a prioritized dig list for use in the remediation of a given site. This dig list must provide accurate horizontal target locations and depths below ground. These locations and depths are currently provided through physics based analyses that provide additional metrics used in the prioritization process. The validity and utility of these analyses are dependent upon the accuracy with which we are able to measure the selected geophysical parameter, locate the measurements in a three dimensional coordinate system, and measure the surface of the ground in this coordinate system. Note that ground based

systems generally collect data at a constant offset from the ground, precluding the additional complexity implied in a 3-D system such as an airborne or marine towed array. In these arrays we must collect both geophysical and altitude sensor data, and spatially position these data to a high degree of accuracy using platform position and attitude measurements, to effect the required analysis.

For any given geophysical UXO investigation, the data processing flow may be logically subdivided into three categories of functional processes: instrumentation specific pre-processing, platform/survey environment specific processing, and data analysis. The pre-processing involves transcription of the raw data files into generic data formats suitable for further manipulation (usually within a database structure). Non-standardized data formats, timing considerations and other factors dictate that this process is specific to the instrumentation manufacturers, and configurations (including that of the data acquisition system). Platform / site specific processing involves data manipulations that are related to the survey platform and/or the survey site conditions. For example, filters required to remove geologic signal from a geophysical data set are dependant upon sensor platform considerations (e.g. stand-off distance and survey speed) and the regional geologic conditions. Data analysis is performed on the final corrected data set and may involve relatively simple threshold based target selection, or more sophisticated techniques such as dipole fitting analysis to derive a final target dig sheet. Data visualization and digital graphics products are important components of this process. Breaking down the data flow into these functional processes permits a modular approach for the migration of the DAS utilities to the Oasis environment, whereby the generic processing and analysis tasks are easily transportable to (and from) suitable systems and/or development projects.

Figure 1 provides an overview of steps taken to convert the raw airborne data to a 3-D positioned magnetic data set suitable for UXO-like target selection and advanced target analyses.

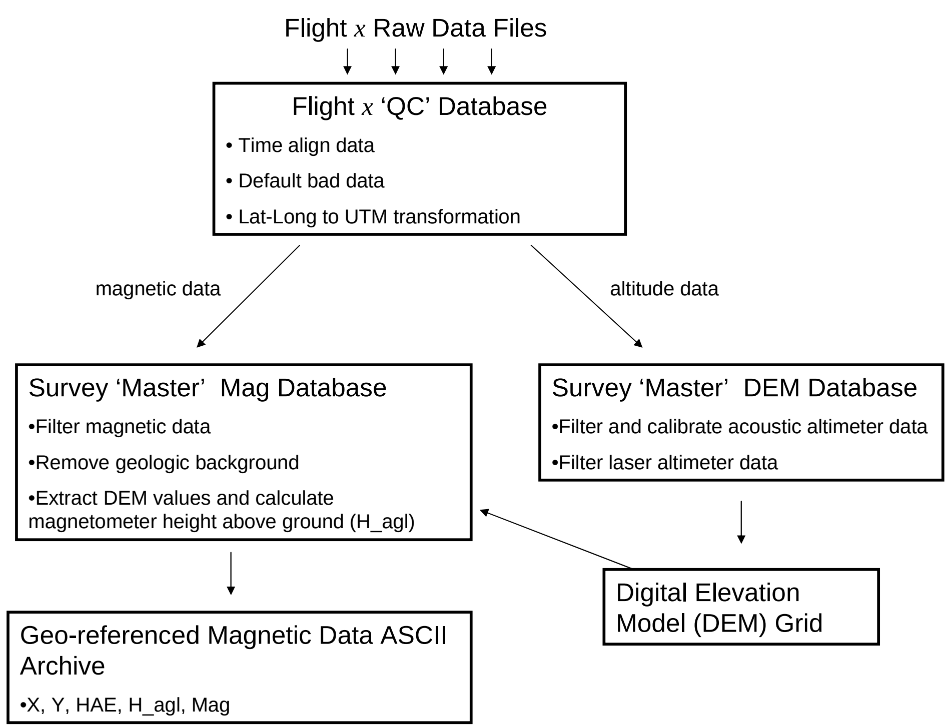

Figure 1. Airborne MTADS data processing flow.

This processing flow is effected in the Oasis processing environment through the use of a custom drop-down menu (**Figure 2**). This menu allows for step by step processing of individual survey flights where the results of each step are easily monitored within the Oasis data environment for quality control purposes. After confirmation that the parameters being used are appropriate for the survey and site conditions, multiple flights may be processed in batch mode to streamline the data reduction process.

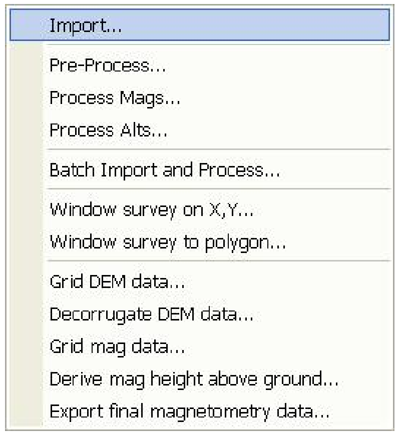

Figure 2. AMTADS main processing drop-down menu

2.1.2 Data Transcription and Pre-Processing

The data transcription process is initiated by selection of the 'Import…' entry in the drop down menu. The user is prompted for the survey flight and the desired UTM coordinate system zone and ellipsoid information.

During this stage the raw data for a given survey flight are time-aligned and transcribed from the various raw data files into a 'flight' database. The GPS geographic position coordinates are transformed to the desired coordinate system (usually WGS84 UTM coordinates are used). At this point the data are visually inspected to ensure both integrity and quality. This transcription stage is instrumentation specific and the steps required to transcribe these data into a time-aligned database are dictated by the structure of the data outputs from each device and the manner in which they are logged. All data outputs are received by the on-board data acquisition computer (DAQ), a DAQ time stamp is appended to each sample data string and the sample is then stored in a separate data file for each device. **Table 1** provides a list of the raw data input files.

An important consideration for integration of the positioning system with geophysical sensors is that of time alignment[2]. For dynamic applications, we need to be able to align the time of applicability (TOA) of our geophysical sensor data with the time of applicability of the measured positioning data to within 1 millisecond. For a survey speed of ~20 m/s this translates to a position error of ~2 cm, on the order of the inherent GPS uncertainty. Any measurement will have some latency before the data are collected and stored. This latency may be static in nature or it may have some variability. In addition to this latency, conventional time stamping of RS232 data is not precise and can inject 100's of milliseconds of additional delays. Thus, simply time stamping the positioning data as it is transmitted to the DAQ does not ensure that the TOA of the positions can be precisely aligned with that of the geophysical data. When the Geometrics

magnetometer consoles are triggered externally, the time lag between this external trigger and the TOA of the magnetometer samples is constant. Thus by using a trigger pulse generated by the DAQ we are able to determine the TOA of the magnetometer data, relative to the DAQ system time.

Table 1. AMTADS raw data summary.

Device	Sample Rate (Hz)	Data Type	Filename.extension	Remarks
Geometrics custom DAQ computer system trigger	100	TTL pulse	TriggerDevice.trig	Generated and logged by the data acquisition computer – initiates the magnetometer sampling
Geometrics Model 822A Cs Magnetometers	100	RS232-ASCII	822A.Mag_a / 822A_Mag_b	7 magnetometers are controlled by 2 consoles – Mag_A sensors 1-4, Mag_B sensors 5-7
Trimble Model MS750 GPS position/attitude data	20/10	RS232-ASCII	GPS.nmea	Position data are in Trimble GGK message format, azimuth and roll are in Trimble AVR message format
Trimble Model MS750 GPS PPS (pulse per second)	1	TTL pulse	PpsDevice.pps	Used to accurately align integer GPS time with DAQ time
Trimble Model MS750 GPS time tag	1	RS232-ASCII	SerialDevice.utc	Used to resolve the integer ambiguity of the GPS PPS signal
Optech Model 60 Laser Altimeter	10	RS232-ASCII	SerialDevice.laser	Measures helicopter height above ground level
Crossbow Tilt meter	10	RS232-Binary	SerialBinDevice.tilt	Used primarily for aircraft pitch measurement
Fluxgate magnetometer	10	RS232-ASCII	SerialDevice.fluxgate	Provides redundant aircraft attitude measurement
Acoustic altimeters	10	Analog voltage	AnalogDevice.analog	Measures sensor array height above ground level at two points

GPS systems commonly have an internal latency that is variable (i.e. the time between the applicability of a given measurement and the transmission of the derived position will vary) in addition to the serial port variability. To allow users to know precisely when a measurement applies, the data message is time stamped (i.e. the position solution is given in 4 dimensions; time, x, y, and z) to a very high degree of precision. In addition GPS receivers will also output a pps (pulse per second) trigger at every precise integer second to provide a means to synchronize the DAQ time with GPS time. The integer ambiguity of the PPS trigger is resolved by sending

the data acquisition system a message (via RS232) that is simply used to assign the precise GPS integer time to the incoming PPS trigger. In this manner, GPS time may be precisely aligned with the DAQ system time.

The steps used to transcribe and time-align the raw data into a single flight database are as follows:

1. For each DAQ trigger event read the corresponding magnetometer data from the Mag_A and Mag_B files and store as a database record. This record will have 7 magnetometer channels and a DAQ time channel.
2. Use the UTC time stamp to assign integer times to the GPS PPS data, interpolate these data into a GPS time channel. This interpolation is based upon alignment of the DAQ time stamp assigned to each PPS with the existing DAQ time channel. This will result in each sample of 7 magnetometer readings having a corresponding DAQ time and GPS time record.
3. Use the GPS time channel and GPS time field in the raw data files to interpolate the GPS position and attitude data for each magnetometer sample. This will result in creation of the following channels in the database: Latitude, Longitude, Height above ellipsoid (HAE), GPS status, AVR yaw (angle of the sensor boom relative to true north), AVR roll (angle of the sensor boom relative to the horizontal plane, and AVR status. The geographic positions represent the positions of the master GPS antenna relative to the WGS84 ellipsoid. The GPS status and AVR status provide a quality of fit indication for the position and attitude data respectively.
4. Use the DAQ time channel and the DAQ time field in the raw data files to interpolate the ancillary data for each magnetometer record. The ancillary data channels include the following: Laser, 4 acoustic altimeter channels (two for each acoustic altimeter station to provide redundancy), tilt meter pitch and roll, and fluxgate x, y, and z components.

After the data are transcribed, a ‘preprocess’ module is run (see **Figure 3**) to automatically reject or ‘default’ invalid data. Data are rejected based upon status flags present in the raw data records or, in the case of the magnetometer data, a simple ‘in range’ test may be used. The GPS and AVR data are defaulted based upon a reasonable range or the values of the two status flags. A 4 pt average filter is applied to the magnetometer data to remove 25 Hz noise commonly found in the AMTADS data (assumed to be vortex shedding). This noise is relatively small in amplitude (less than 0.5 nT and, as a result this filter has very little effect on the data.

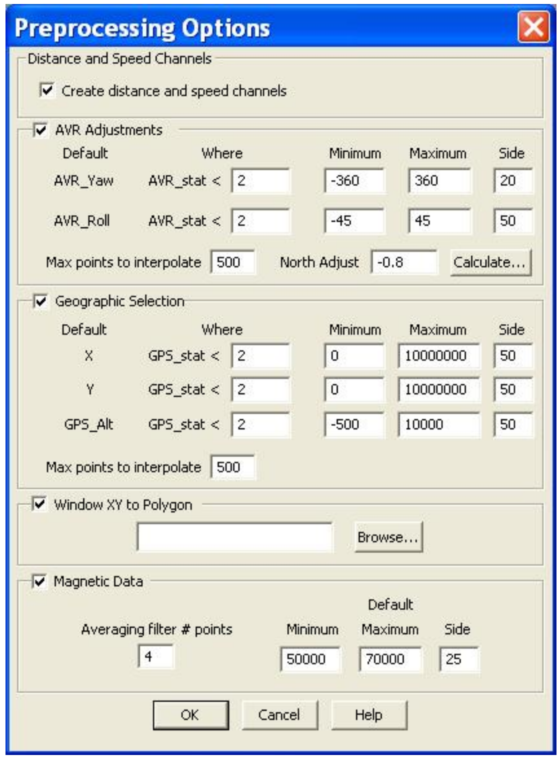

Figure 3. AMTADS preprocessing drop-down menu

2.1.3 Processing

During the processing stage the magnetometer and altimetry data are positioned and exported to ‘master’ or ‘site’ survey databases. For each contiguous survey area a master magnetometer database and a master altimeter database are created. The altimeter database is used to create a digital elevation model (DEM) that is used to derive the height above ground for each magnetometer reading. Each of these ‘master’ databases will contain data from a number of sorties. The magnetometer and altimetry data are positioned by transforming the master GPS antenna positions to each of the sensors based upon the aircraft orientation relative to the WGS84 ellipsoid and the geometry of each sensor relative to the master antenna.

After the geo-located magnetometry data are positioned and loaded into the master magnetometer database they undergo filtering as dictated by the survey site conditions and survey objectives. In **Figure 4** we show the interface used when exporting magnetometry data from the QC data base to the master site database.

Geophysical data, as collected in a geo-referenced survey, is comprised of broadband information derived from the combined effects of numerous sources, which include geology, culture, transient terrestrial and cosmological sources, in addition to instrument characteristics and survey methodology. The response of interest versus that of various noise sources is often not obvious and there can be considerable overlap in the range and power of the characteristics of the signals of interest and the noise. In an effort to solve this problem, spatial and frequency domain filters are commonly applied to geophysical data to enhance those parts of the signal that are of interest by removing or minimizing unwanted noise components prior to further data manipulation and interpretation. When using geophysical surveys for the detection of unexploded ordnance (UXO), we define any response from a UXO-like object as our signal,

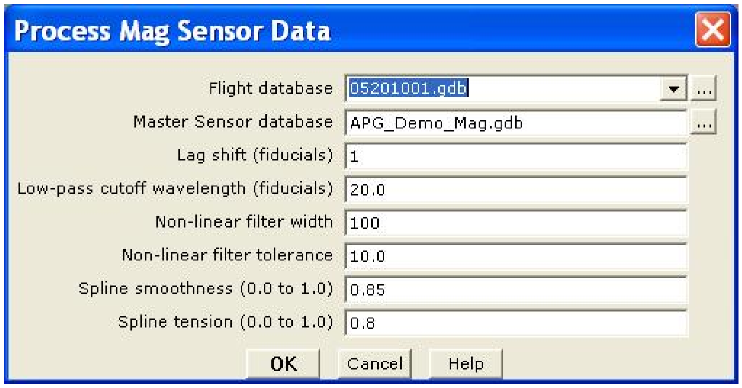

Figure 4. AMTADS 'process mags' drop-down menu. The low-pass filter removes high frequency noise. The 20pt (5Hz) cut-off is designed to reduce the rotor noise (6.5 Hz) and vibration noise (25Hz)

and endeavor to remove the unwanted signal from all other sources that we would characterize as ‘noise’. The initial detection of UXO and UXO-like targets is primarily based upon the spatial response attributed to the target. For the AMTADS system we assume a relatively consistent survey speed and use a series of frequency based filters to reduce noise and enhance the signals with spatial responses appropriate for UXO.

The first filter used is designed to remove the influence of the helicopter platform on the measured data. The high frequency components of these signals (primarily blade noise (13 Hz) and rotor noise (6.5 Hz) are commonly removed through the use of a low-pass filter with a roll-off value of 20 pts (5 Hz at our 100 Hz sample rate).

In a typical UXO survey, the relatively short periodicity of UXO targets allows us to remove the aircraft orientation effects, long wavelength geologic effects and magnetic diurnal drift using time or spatial based filtering techniques. The next set of filters removes these long wavelength signals from the data. To do this we use two filters to derive a ‘long-wavelength model’ that is then subtracted from the low-pass filtered, total field data to provide a ‘final’ total magnetic field data set. The first filter is a non-linear filter that allows us to reject short-wavelength/high amplitude anomalies from the data so that they do not distort the effect of the smoothing filters that are subsequently used to create the long wavelength model.

The first filter is considered ‘non-linear’ because it modifies only those data that fall outside the specified amplitude/width criteria (linear filters will modify all data). In order to be considered noise, a feature must be narrower than the specified width (in number of data points) and of greater amplitude than a specified amplitude tolerance. We specify 100pts as the width – this equates to a nominal ground distance of 20m which is significantly larger than the spatial extent of typical UXO responses at our survey altitude. Larger widths are also acceptable but result in slower performance. A 10 nT amplitude cut-off is sufficient to minimize the amplitude of the effect of small wavelength features in the subsequent smoothing filter output.

In the example shown above the smoothing filter of choice is a B-spline filter. While a simple low-pass filter may also be used to derive the long-wavelength model, the B-Spline filter allows us to fine-tune the final model with respect to the smoothness of the model variations. This fine-tuning is performed interactively on a subset of the data until the desired results are achieved. The B-Spline filter is computationally much faster than the low-pass filter, thus facilitating the interactive process. The parameters provided in **Figure 4** are appropriate for most site

conditions, however the smoothness parameter can range from 0.75 to 0.85 (the 'tension' has little effect for this application of the filter).

It bears note that as the sensor to target stand-off distance increases, the response periodicity of our intended detection targets also increases, requiring modification of the chronologic and spatial filters we employ.

The original DAS prototype relied upon the use of a simple 500-point de-median filter. Moving to the Oasis environment provides the ability to apply a number of different filtering techniques and quickly assess their performance. In **Figure 5** we compare the prototype DAS results with those obtained using both a de-median filter and a combination non-linear/b-spline filter in the Oasis environment. The de-median filter appears to remove some smaller/broader anomalies and distorts the data adjacent to sinusoidal shaped anomalies.

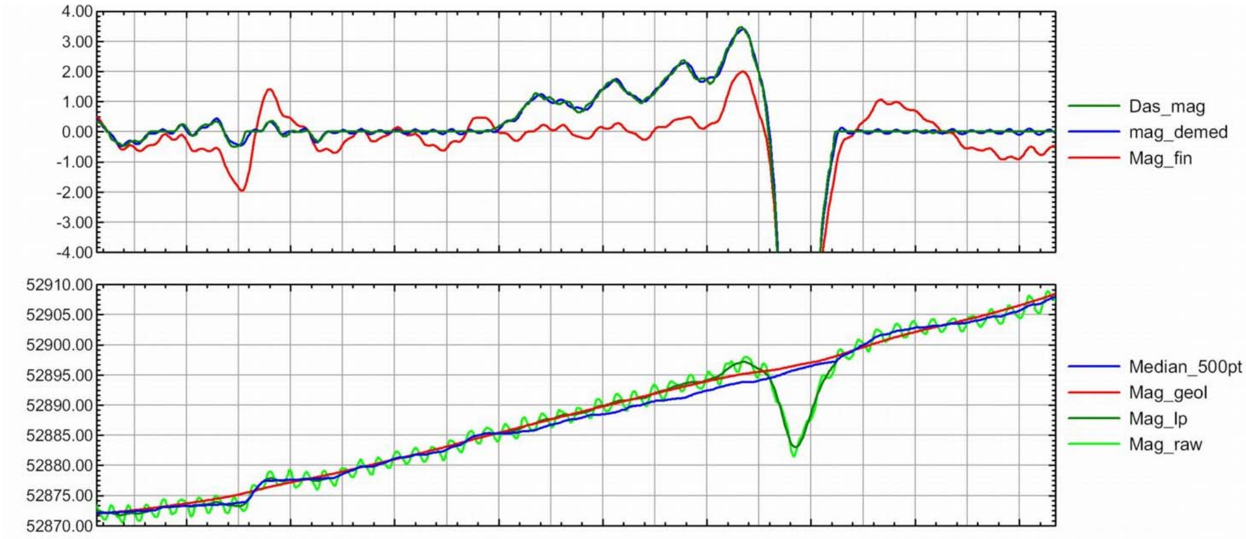

Figure 5. Comparison of de-median filter with combination nonlinear/bspline filter for removal of long wavelength signal from the AMTADS magnetometry data. In the bottom panel the long wavelength 'background' data are superimposed over the raw data. The top panel shows the final 'background removed' data. The DAS_mag channel is the final mag as supplied by the DAS. The Mag_demed and Mag_fin are the de-median and combination non-linear/b-spline results respectively.

The altimetry data are loaded into the DEM database using an interface similar to that used for the magnetometry. The AMTADS system uses both acoustic and laser altimeters. Because the laser altimeter is relatively heavy it cannot be mounted on the forward boom and is offset from the boom by approximately 6 m. This offset results in added uncertainty in the vertical positioning of the laser data relative to the master GPS antenna (and in the resultant DEM model) due to the accuracy of the aircraft pitch measurements. The acoustic altimeters are mounted directly under the GPS antennae and the positioning of these data is not affected by the aircraft pitch. However, low vegetation cover will degrade the measurement accuracy of these altimeters. Therefore, depending upon the site conditions, the user has a choice of using the acoustic altimeters, laser altimeter or both technologies to deriving the DEM. The DEM is an estimate of the ground elevation relative to the WGS84 ellipsoid. After the DEM grid has been produced, DEM data are extracted for each geo-referenced magnetometer sensor measurement. The height above ground for each of these measurements is then determined by subtracting the DEM value from the magnetometer height above the ellipsoid.

After deriving a geo-referenced, total magnetic field data set that is filtered to maximize the SNR of UXO-like objects, anomaly selections and dipole fit analyses of individual targets may be performed. This analysis iteratively attempts to find the dipole model that best fits the local magnetic response over a selected target.[3] The parameters of this model including position, size, dipole orientation, and fit coherence are used to draw conclusions regarding the likelihood of the target being UXO, and its equivalent size. These conclusions and the position and depth data are then used to guide subsequent UXO remediation efforts.

3 Testing and Evaluation

3.1 Initial Development and Testing

The algorithms initially developed for the DAS prototype have been incorporated into the Oasis environment in a gradual manner. During the original AMTADS development project reformatting macros and scripts were developed somewhat in parallel with the DAS (preprocessing) development. This was done to take advantage of the existing data viewing and manipulation capabilities of Oasis, as well as to provide an independent check of the preprocessing and filtering performed with the DAS.

The DAS was used for all preprocessing and filtering during the initial validation demonstrations of the AMTADS system. Prior to the demonstration performed at the Isleta Pueblo in New Mexico[4], a numerical comparison confirmed that the pre-processing results using the Oasis environment were in agreement with those obtained using the DAS. The decision to use the Oasis approach for preprocessing and filtering of the Isleta data was made to take advantage of the data viewing and filtering options available with Oasis.

As the Oasis based software became available it was used in support of a number of surveys that were undertaken by Sky Research including projects at the FLBGR, CO; Camp Lejeune, NC, Pueblo Precision Bombing Range, CO; Kirtland Precision Bombing Range, NM; and the Victorville Precision Bombing Range, CA. Once again, numerical comparison of the preprocessed results was the basis for testing of this software. The results from each new version of the software was compared numerically with the results obtained with the original Oasis based scripts and macros. During this ‘de-bugging’ process a large number of code revisions were required. Many of these revisions were necessitated by changes in the system hardware or raw data formats and others were required to improve the robustness of the software in its handling of minor glitches and discontinuities in the raw data.

The validity of the data processed using the new Oasis software was verified by comparison of dipole fit results with ground truth for a small set of emplaced targets. As an example, a calibration lane was established for the survey flown at the Kirtland Precision Bombing Range. This line was seeded with the 8 targets listed in **Table 2** and was flown at the start and end of each day of data collection.

Table 2. Kirtland WAA calibration lane targets.

ID	X	Y	Azimuth	Description
1001	336150.50	3892199.66	351° 39' 54"	Simulated 100 lb bomb
1002	336100.32	3892199.41	357° 33' 40"	155 mm projectile
1003	336049.92	3892199.93	10° 35' 35"	Metal cache box
1004	336000.56	3892199.55	357° 49' 17"	2.75” rocket

1005	335950.40	3892199.75	358° 12' 01"	Simulated 100 lb bomb
1006	335899.92	3892199.43	353° 12' 27"	155 mm projectile
1007	335850.62	3892199.49	6° 49' 18"	Metal cache box
1008	335800.55	3892199.69	358° 24' 17"	2.75” rocket

The data collected over each target from the cal line passes were analyzed with the MTADS dipole fit algorithm (using the UX Analyze environment). This analysis derives the parameters for a model dipole that best fits the observed data. These parameters include horizontal position, depth, size, and solid angle (i.e. the angle between the Earth’s magnetic field vector and that of the dipole model).The derived parameters were examined for accuracy, (determined as the average error where relevant), and repeatability (indicated by the standard deviation), presented in **Table 3**. For the standard deviation calculations, biases particular to each individual target are removed prior to calculating the standard deviation for the entire set of measurements.

Table 3. Kirtland WAA calibration lane results.

Dipole Fit Parameter	Bias	Standard Deviation
Easting	0.02 m	0.09 m
Northing	0.06 m	0.13 m
Depth	0.15 m	0.13 m
Size	n/a	7 mm
Solid Angle	n/a	6.0 °

In **Figure 6** we show the derived positions for each target relative to the ground truth supplied. The accuracy of these positions relative to the ground truth is well within the range expected for the AMTADS system. The increased noise in the northing is assumed to be a result of the relative sample densities for each direction. (the calibration lines were flown in an east-west direction and along-track sample density is 5 to 10 times higher than for across-track). This is consistent with our findings from the Pueblo calibration line data where the lines were flown in a north-south direction and the easting positions showed more variation.

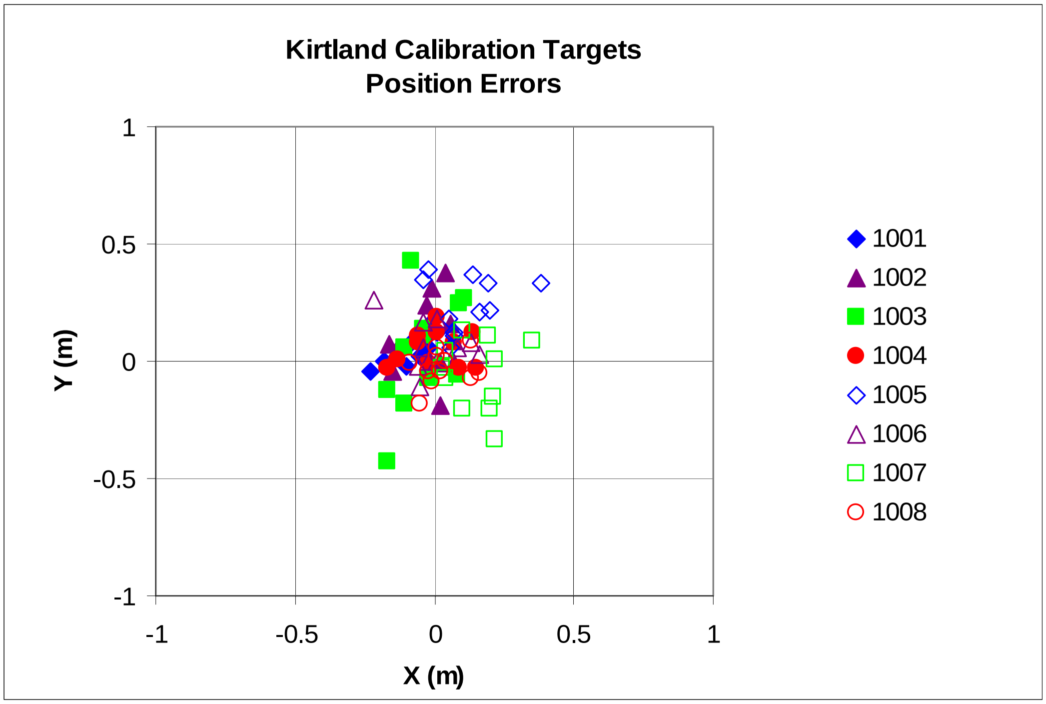

Figure 6. Derived x and y coordinates for the calibration targets relative to the supplied ground truth.

In the dipole fit depth estimates (**Figure 7**) it appears that the depths are too deep by an average of 0.15 m. As surmised for the Pueblo calibration line results, this bias is most likely due to the grassy vegetative cover over the calibration area.

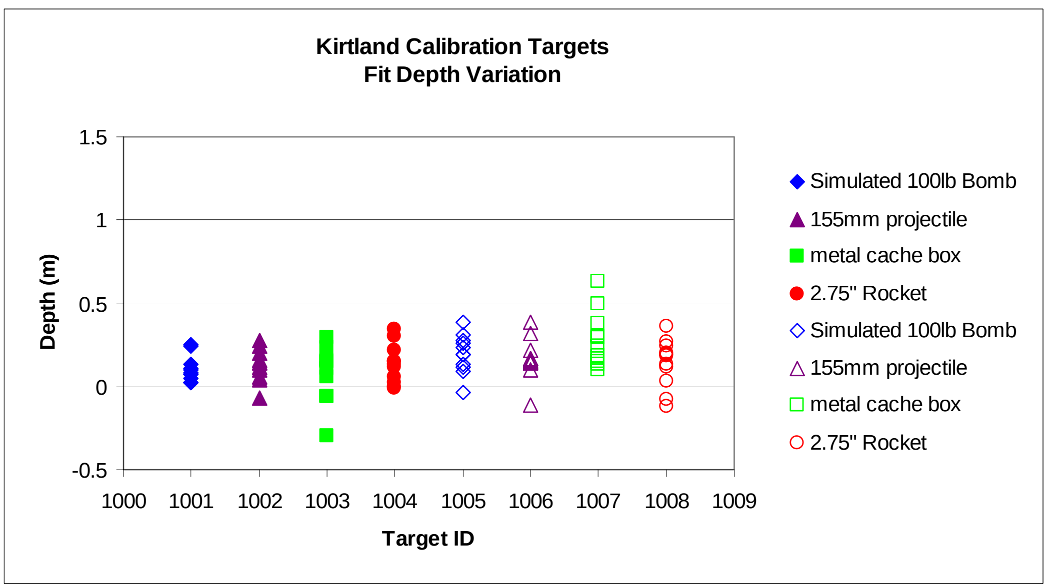

Figure 7. Dipole fit depth estimates for calibration line targets.

The dipole fit size estimate for any given ordinance will vary considerably depending upon the alignment of the object with the Earth's magnetic field. Therefore the size can only be used as a coarse estimate of the object size. For this reason, the accuracy of the size estimate of the

calibration items is not of particular import when discussing the system performance, other than simply verifying that the estimate falls within the expected range for a given target (which they do, as shown in **Figure 8** where, for example, the 155mm projectile results in a fitted size ranging from 125mm to 185mm). Because the calibration data consist of repeated flights over the same stationary targets, we can look at the repeatability of the derived size estimates as an indication of consistent system performance.

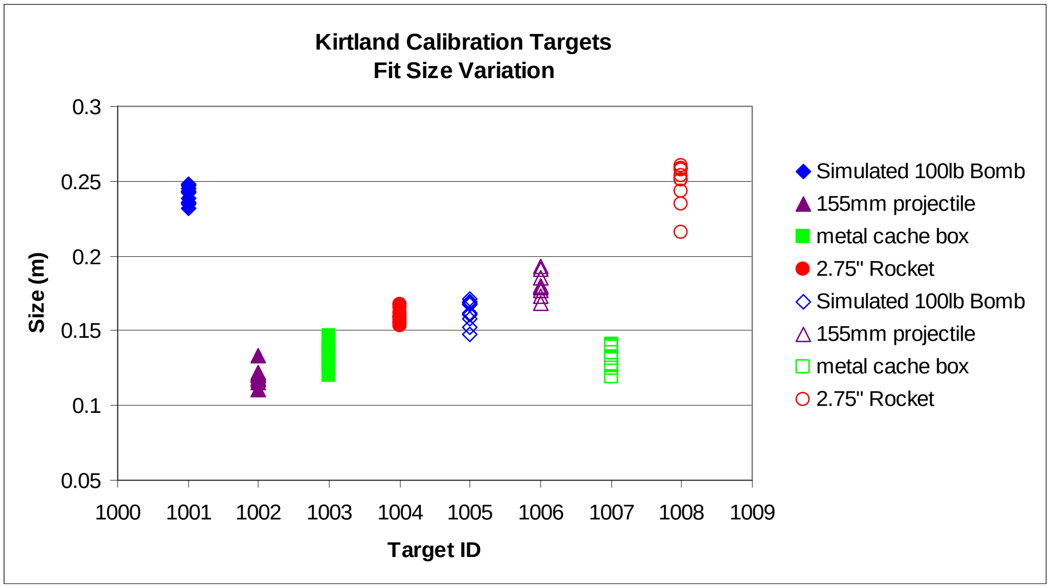

Figure 8. Dipole fit size estimates for calibration line targets.

In a manner similar to the size estimates discussed above, the dipole fit solid angle estimates depend heavily on the orientation of the target relative to the Earth's magnetic field. In the case of the calibration line test targets, the 'ground truth' is unknown and not really important. However the stability of this prediction for repeated flights over the calibration line is indicative of the performance of the airborne system. Figure 9 shows the reproducibility of this parameter.

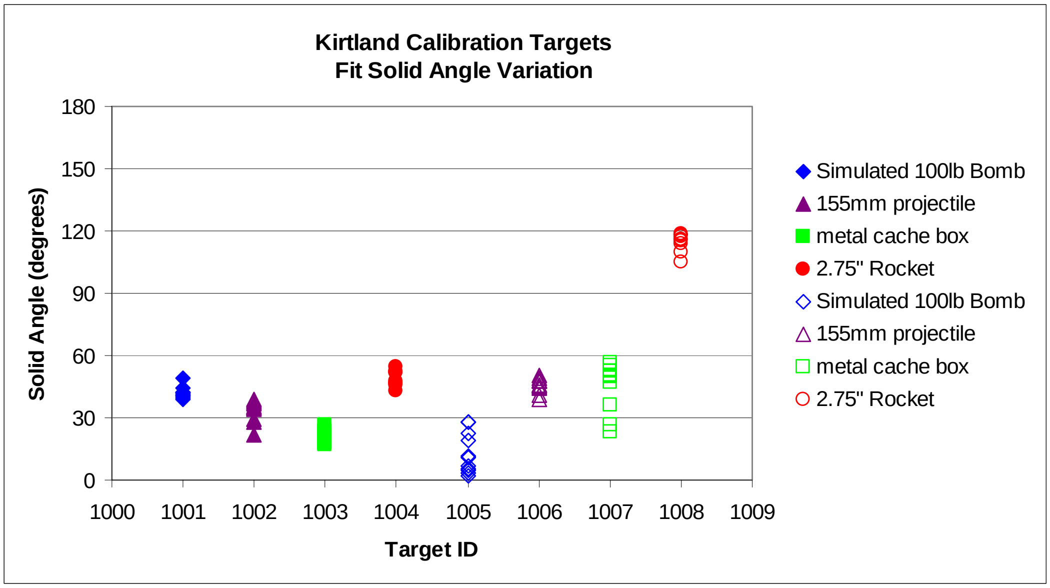

Figure 9. Dipole fit solid angle estimate for calibration line targets.

3.2 3D Visualization

The original project plan included provision for improving the tools available to visualize the AMTADS data in three dimensions. This capability applies to viewing of individual target data and is by necessity imbedded in the dipole fit analysis routine. The dipole fit routines are being transitioned to the Oasis environment under a separate project. Due to competing priorities, 3D target visualization is not implemented at the time of this report.

3.3 Validation

Final validation of the developed software was performed by comparison of Oasis-based software results with those obtained using the original DAS. The original DAS was used to process a demonstration survey at the Aberdeen Proving Ground[5] in July, 2002. As part of this demonstration a test survey was flown over an airfield where independent ground truth is available in the form of 52 emplaced targets. The Oasis-based software was used to reprocess these data (**Figure 10**). Because the filters used in the new data were not identical to the de-median filter used in the original DAS, a simple numerical comparison of the two data sets reveals slight differences but it is not possible to judge if these differences are significant and, if so, which data set is more accurate.

To address this question, dipole-fit analyses were performed for each emplaced target using the reprocessed data set so that the accuracy of these results may be compared with the accuracy of the original dipole fit results. The dipole fit analysis derives features of a magnetic dipole that best fit the observed data over a selected target. These features include 3D position, dipole size, dipole orientation and fit coherence. While dipole size and orientation are useful for prioritization of a dig list, they are not independently verifiable and as such are not useful in determining the relative accuracy of the two data sets in question. Thus we are left with the target position estimates as parameters that are independently verifiable, and fit coherence as a measure of the relative consistency of the data used for each fit.

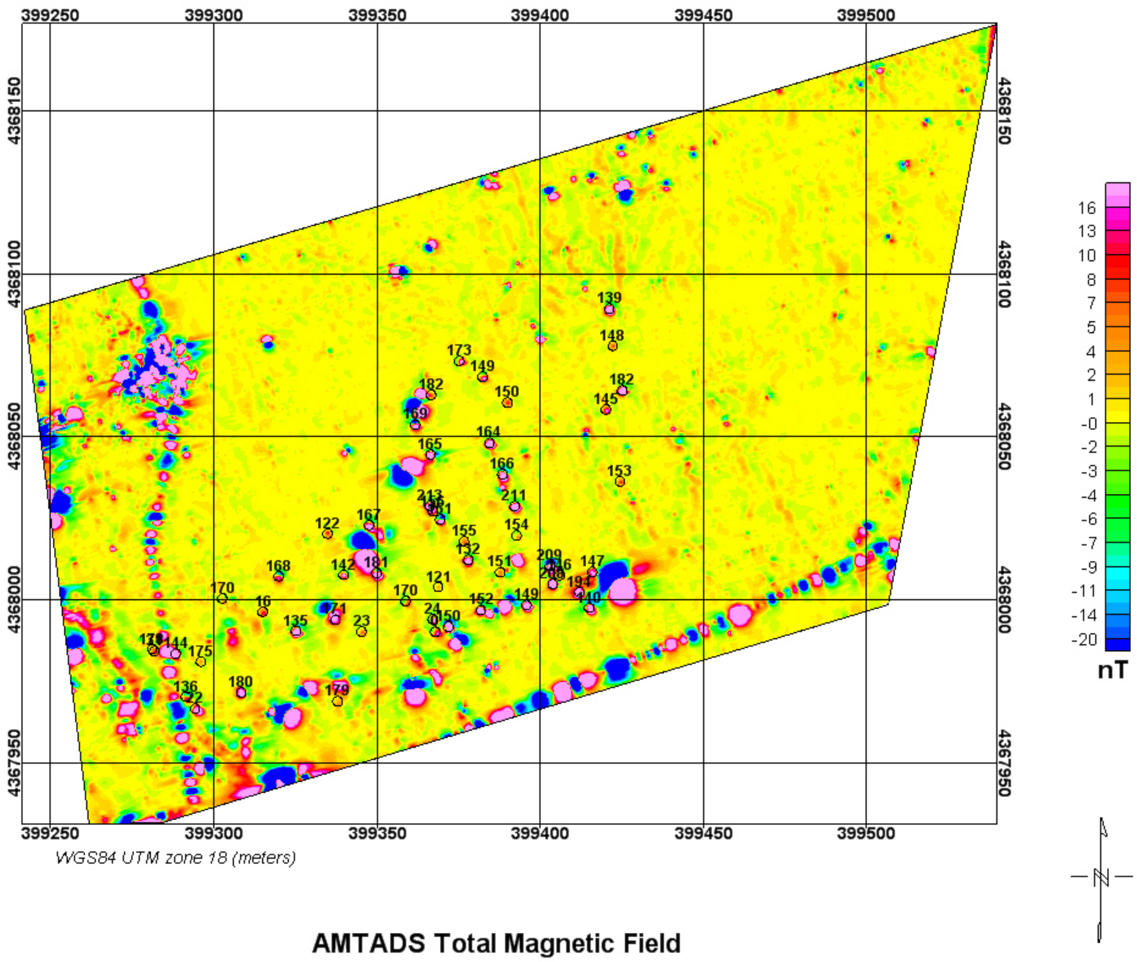

Figure 10. Reprocessed total magnetic field data with emplaced targets over the airfield site.

Of the 52 emplaced targets, dipole fits were obtained for 34 of them (originally 46 were detected but only 34 were successfully fit to a dipole model). In **Table 4** we show the average (bias) and standard deviation of the errors in the derived positions relative to the supplied ground truth. As one might expect, there appears to be very little difference in the results obtained using the DAS and Oasis processing methodologies. The slight advantage shown in the fit coherence of the Oasis results is probably due to incremental improvements in the filtering methodology. This may also explain the improvement in the depth estimates because this feature is strongly influenced by the apparent wavelength of the anomaly.

Table 4. Dipole fit results for the original DAS and the Oasis-based software.

Parameter	DAS	Oasis
Easting bias (m)	0.03	0.02
Easting standard deviation (m)	0.19	0.11
Northing bias (m)	0.07	0.12
Northing standard deviation (m)	0.23	0.26
Depth bias (m)	-0.02	-0.07
Depth standard deviation (m)	0.38	0.24
Coherence (average)	0.891	0.920

4 Summary

The MTADS data processing methodology that was developed and vetted as part of the ESTCP program MM-0031 has been transferred to the commercially available Oasis Montaj geophysical processing environment. The resulting processing routines have been modularized so that the instrumentation specific front end is separate form the site specific routines. The original functionality of the MTADS software is maintained or improved. The Oasis-based software has successfully tested against the original MTADS directly and has also been used on a number of WAA demonstration projects.

5 References

1. “Airborne UXO surveys using the MTADS” H.H. Nelson, J.R. McDonald, D.J. Wright, NRL/MR/6110--05-8874, April 5, 2005

2. “Careful Timing is the Key to Sensor Location Accuracy” H.H. Nelson. Proceedings UXO/ Countermine Forum 2001.

3. “Magnetic modeling of UXO and UXO-like targets and comparison with signatures measured by MTADS,” Nelson, H., Alshuler,T., Rosen, E., McDonald, J., Barrow, B., and Khadr, N., UXO Forum 1998, Anaheim, California, May 5-7, 1998.

4. “MTADS Airborne and Vehicular Survey of Target S1 at Isleta Pueblo, Albuquerque, NM, 17 February-2 March 2003,” H.H.Nelson, David Wright, Tom Furuya, J.R. McDonald, Nagi Khadr, and D.A. Steinhurst, NRL/MR/6110--04-8764, March 31, 2004.

5. “Airborne MTADS demonstration at the Aberdeen Proving Ground," H.H. Nelson, J.R. McDonald, David Wright, Nagi Khadr, NRL/MR/6110--04-8855, January 12, 2005.

Appendix A

IDA				DAS							Oasis						
ID	X	Y	Z	Fit_X	Fit_Y	Depth	Fit_Coh	X_err	Y_Err	Z_err	Fit_X	Fit_Y	Depth	Fit_Coh	X_err	Y_Err	Z_err
209.00	399402.96	4368010.45	0.09	399402.93	4368010.43	0.34	0.995	0.02	0.03	-0.25	399402.94	4368010.42	0.33	0.996	0.03	0.02	-0.24
151.00	399369.32	4368024.71	0.09	399369.32	4368024.68	0.14	0.965	0.01	0.05	-0.05	399369.31	4368024.66	0.13	0.987	0.00	0.03	-0.04
182.50	399425.06	4368064.27	0.46	399425.04	4368064.31	0.58	0.983	0.07	0.13	-0.12	399424.99	4368064.14	0.54	0.840	0.02	-0.04	-0.08
167.00	399347.54	4368023.05	0.46	399347.48	4368023.03	0.61	0.943	0.08	0.27	-0.15	399347.46	4368022.78	0.67	0.917	0.06	0.02	-0.21
136.00	399291.42	4367970.33	0.46	399291.46	4367970.27	0.09	0.913	-0.08	0.08	0.37	399291.49	4367970.25	0.20	0.976	-0.05	0.06	0.26
168.00	399319.78	4368007.30	0.46	399319.76	4368007.37	0.53	0.961	0.03	-0.04	-0.07	399319.75	4368007.34	0.46	0.979	0.02	-0.07	0.00
169.00	399361.56	4368053.83	0.46	399361.50	4368053.91	0.77	0.873	0.00	0.15	-0.31	399361.56	4368053.68	1.00	0.935	0.06	-0.08	-0.54
180.00	399308.42	4367971.61	0.09	399308.32	4367971.58	0.63	0.865	0.36	0.07	-0.54	399308.06	4367971.54	0.37	0.992	0.10	0.03	-0.28
150.00	399371.82	4367991.85	0.09	399371.74	4367991.77	0.24	0.978	0.08	0.19	-0.15	399371.74	4367991.66	0.31	0.915	0.08	0.08	-0.22
165.00	399366.42	4368044.64	0.09	399366.44	4368044.79	0.26	0.877	-0.05	-0.10	-0.17	399366.47	4368044.74	0.26	0.880	-0.02	-0.15	-0.17
208.00	399403.76	4368004.94	0.09	399403.66	4368004.82	0.33	0.986	0.23	0.07	-0.24	399403.53	4368004.87	0.35	0.989	0.10	0.12	-0.26
142.00	399339.72	4368007.70	0.09	399339.63	4368007.54	0.22	0.977	0.14	0.09	-0.13	399339.58	4368007.61	0.15	0.956	0.09	0.16	-0.06
145.00	399420.12	4368058.48	0.11	399419.99	4368058.62	0.47	0.959	0.01	0.06	-0.36	399420.11	4368058.42	0.30	0.874	0.13	-0.14	-0.19
213.00	399366.15	4368028.81	0.82	399366.24	4368028.62	0.66	0.950	-0.18	-0.03	0.16	399366.33	4368028.84	0.78	0.980	-0.09	0.19	0.04
149.00	399382.34	4368068.55	0.11	399382.29	4368068.76	-0.06	0.919	0.08	-0.12	0.17	399382.26	4368068.67	0.10	0.956	0.05	-0.21	0.01
170.50	399358.73	4367999.69	0.82	399358.68	4367999.47	0.45	0.943	0.06	0.02	0.37	399358.67	4367999.67	0.44	0.941	0.05	0.22	0.38
173.00	399375.14	4368073.42	0.46	399375.33	4368073.28	0.04	0.908	-0.09	-0.28	0.42	399375.23	4368073.70	0.31	0.845	-0.19	0.14	0.15
122.00	399334.80	4368020.44	0.53	399334.58	4368020.55	0.20	0.641	0.10	-0.17	0.33	399334.70	4368020.61	0.31	0.764	0.22	-0.11	0.22
139.00	399421.12	4368089.39	0.46	399421.07	4368089.14	0.60	0.980	0.05	0.26	-0.14	399421.07	4368089.13	0.71	0.987	0.05	0.25	-0.25
140.00	399415.04	4367997.58	0.46	399415.15	4367997.35	0.54	0.891	-0.28	0.25	-0.08	399415.32	4367997.33	1.14	0.907	-0.11	0.23	-0.68
148.00	399422.22	4368078.02	0.53	399422.19	4368078.30	0.18	0.679	0.19	-0.42	0.35	399422.03	4368078.44	0.38	0.894	0.03	-0.28	0.15
166.00	399388.42	4368038.57	0.46	399388.46	4368038.29	0.62	0.984	-0.04	0.37	-0.16	399388.46	4368038.20	0.55	0.969	-0.04	0.28	-0.09
150.50	399389.87	4368060.58	0.53	399389.98	4368060.30	0.31	0.852	-0.20	0.07	0.22	399390.07	4368060.51	0.56	0.927	-0.11	0.28	-0.03
154.00	399392.74	4368019.85	0.53	399392.79	4368019.55	0.14	0.901	0.01	0.12	0.39	399392.73	4368019.73	0.18	0.885	-0.05	0.30	0.35
211.00	399392.07	4368028.81	0.46	399392.17	4368028.51	0.48	0.955	0.00	0.29	-0.02	399392.07	4368028.52	0.66	0.990	-0.10	0.30	-0.20
23.00	399345.18	4367990.29	0.00	399345.32	4367990.01	0.13	0.914	-0.18	0.22	-0.13	399345.36	4367990.07	0.15	0.913	-0.14	0.28	-0.15
149.50	399395.73	4367998.39	0.46	399395.78	4367998.06	0.53	0.978	0.13	0.01	-0.07	399395.60	4367998.38	0.48	0.883	-0.05	0.33	-0.02
135.00	399325.06	4367990.52	0.09	399325.17	4367990.16	0.44	0.985	-0.11	0.27	-0.35	399325.17	4367990.25	0.50	0.986	-0.11	0.36	-0.41
155.00	399376.61	4368018.01	0.53	399376.51	4368017.63	0.21	0.695	0.41	-0.13	0.32	399376.20	4368018.14	0.48	0.859	0.10	0.38	0.05
152.00	399381.76	4367996.88	0.46	399381.38	4367997.01	0.28	0.636	0.46	-0.13	0.18	399381.30	4367997.01	0.30	0.816	0.38	-0.13	0.16
132.00	399377.91	4368012.32	0.82	399377.74	4368011.85	0.60	0.908	0.16	0.24	0.22	399377.75	4368012.08	0.67	0.979	0.17	0.47	0.15
194.00	399412.02	4368002.37	0.82	399411.95	4368001.83	2.36	0.759	-0.53	0.27	-1.54	399412.55	4368002.10	1.06	0.944	0.07	0.54	-0.24
153.00	399424.43	4368036.37	0.53	399424.32	4368036.99	-0.08	0.787	0.13	-0.59	0.61	399424.30	4368036.96	0.34	0.802	0.11	-0.62	0.19
24.00	399367.13	4367994.10	0.11	399367.26	4367993.44	0.00	0.768	-0.06	0.67	0.11	399367.19	4367993.43	0.14	0.811	-0.13	0.66	-0.03
					Average (bias)		**0.891**	**0.03**	**0.07**	**-0.02**		**Average (bias)**		**0.920**	**0.02**	**0.11**	**-0.07**
					Standard Deviation			**0.19**	**0.23**	**0.38**		**Standard Deviation**			**0.12**	**0.26**	**0.24**